

Aberystwyth University

Historical records, archives, and photogrammetry

Wilson, Andrew; Miles, Helen; Labrosse, Frédéric; Tiddeman, Bernie; Roberts, Jonathan

Published in:

The Historic Environment: Policy & Practice

DOI:

[10.1080/17567505.2016.1142696](https://doi.org/10.1080/17567505.2016.1142696)

Publication date:

2016

Citation for published version (APA):

Wilson, A., Miles, H., Labrosse, F., Tiddeman, B., & Roberts, J. (2016). Historical records, archives, and photogrammetry. *The Historic Environment: Policy & Practice*, 7(1), 25-42.
<https://doi.org/10.1080/17567505.2016.1142696>

General rights

Copyright and moral rights for the publications made accessible in the Aberystwyth Research Portal (the Institutional Repository) are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the Aberystwyth Research Portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the Aberystwyth Research Portal

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

tel: +44 1970 62 2400
email: is@aber.ac.uk

Historical Records, Archives and Photogrammetry

Andrew T. Wilson[†], Helen C. Miles*, Frédéric Labrosse*,
Bernard Tiddeman*, and Jonathan C. Roberts[†]

[†] School of Computer Science, Bangor University, Bangor, UK.

* Department of Computer Science, Aberystwyth University, Aberystwyth, UK.

Abstract—Archaeological heritage is part of a global identity; the need to preserve this heritage is important, not only to the local communities in which it is present but also to national and international communities. In recent year, digital recordings of monuments and buildings have provided significant contributions in the preservation, presentation and dissemination of cultural heritage. Digital recording of cultural heritage is a multidimensional and complex process: not only does it require researchers to address the problem of 3D digitisation of the monuments but also other aspects of this handling this new digital content, such as management, representation and reproduction. Various techniques have been proposed and different technologies have been developed: some based on laser scanning, others on photogrammetric techniques, some using simple empirical methodologies and others based on imaging techniques. However these techniques focus on cultural heritage assets which are still in existence. For lost, destroyed or damaged heritage, all that remains in a visual context are archived images. We investigate the use of photogrammetry on archived images, to attempt to create 3D reconstructions of lost heritage assets.

Index Terms—Structure-from-Motion, archaeology, heritage, 3D model.

I. INTRODUCTION

The use of photogrammetry to construct 3D models of objects from a set of 2D images has become a common technique in archaeology in the last decade. Used to document sites, the excavation process and objects in museums, photogrammetry has become popular as a method thanks to the ease of producing data. Powerful software now performs much of the task, requiring only a good set of photographs to produce a model.

The software is now robust enough to be able to reconstruct 3D models from low-resolution images from uncalibrated cameras. This opens up the possibility of generating models of sites from older photographs, which is particularly valuable for sites which have since been destroyed or significantly altered.

This paper investigates the possibilities of a using

photogrammetry for the 3D documentation of archived archaeological data, considering different sources types of data. We discuss whether automated photogrammetry on archived images enables the creation of suitable 3D models of heritage assets, particularly those already destroyed and only visually preserved in 2D photographic records.

II. RELATED WORK

Examples of the use of archive data in the creation of 3D models of heritage sites are scarce. Grussenmeyer & Yasmine used aerial photographs recorded in the French air force in the 1930s in combination with newer photographs to create a 3D model of the landscape around Beaufort Castle in Lebanon (2004). Orengo & Fiz did not use photogrammetry, but archived photos were used to aid in the creation of a topographical model of the coastline and urban areas of ancient Tarraco (2007). In both of these examples, the archive images were successfully used to create 3D models for use in the analysis of the site.

Kalisperakis et al. created a 3D model of the lost ‘Tsopotos’ residence, a building originally in the centre of Athens, from five historical photographs (2003). The authors were focused on calculating the camera calibration parameters using both commercial and software developed in-house to compare the results; they found that despite having less manual control over the commercial software package, PhotoModeler, comparable models were produced.

Outside of the reconstruction of archaeological sites of interest, archived and historical aerial images have been used in the assessment of landslide progression (Walstra et al. 2007), where the traditional form of photogrammetry – using photographs to make measurements – was used to measure the location of boulders over time. The photographs were used to create digital elevations models and orthophotos.

III. ARCHIVE SOURCES

In the UK, different types of archives often hold similar material but for different purposes and in different formats. Regional and national trusts hold records specific to geographical areas, while collections also cover specific sets such as excavations run by a university, or types of photographs such as maritime or aerial.

A. Regional Archives

An example of an archive maintained by a regional trust is the Historic Environment Record (HER) of Gwynedd Archaeological Trust (GAT). The trust is one of the four Welsh Archaeological Trusts (WAT), alongside Dyfed (DAT), Clwyd-Powys (CPAT) and Glamorgan-Gwent (GGAT) which each manage a local area in Wales, UK.

Local community volunteers are currently digitizing historical records and archive data from GAT. Approximately 500,000 photographs, from modern day to antiquity, document numerous commercial surveys and excavation work undertaken by GAT in North Wales. The archive contains various types of images, including aerial and terrestrial photographs in colour, black and white, or sepia. The photographs from commercial surveys often document sites that have been radically changed or even destroyed since the survey was taken, therefore providing the only remaining record of some heritage sites in North-West Wales. The photographic collections are not available online through GAT, but the HER can be searched online using Archwilio, the online data service shared between the four WATs.

B. National Archives

Trusts also exist on a national scale: the Royal Commission on the Ancient and Historical Monuments of Wales (RCAHMW), the Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS), Cadw, the Welsh Government's historic environment service and English Heritage (EH) all maintain their own archives.

Some overlap does exist between regional and national archives, for example: RCAHMW maintain both their own data and subsets of data collected from each of the four WATs. RCAHMW are receiving updated collections from the four trusts periodically, as well as working to digitise their own collections which are held in hard copies at the National Monuments Record (NMR) in Aberystwyth. Traditionally, the NMR archives are searched by making an appointment to view the

photographs (and other data), which are prepared in advance by an archivist.

The year 2014 marks the 10-year anniversary of Coflein, the online digital archive provided by RCAHMW. This service provides free online access to the content currently digitised by RCAHMW and the four WATs, including reports in PDF and text format and images (photographs, illustrations, paintings, postcards, etc.); images are only available through Coflein in low resolution (800 × 600 pixels), high resolution images must be ordered via the Library and Reader Services but are subject to copy and licensing fees.

C. Collection Archives

Some archives are based on a type of material or a theme. Examples of these 'collection archives' include the People's Collection Wales (PCW), the Archaeology Data Service (ADS), Britain From Above (BFA) and the Portable Antiquities Scheme (PAS).

PCW is an archive which collects different types of data relating to the history of Wales, both from archaeologists and contributing members of the public. It accepts not only photographs, but film, sound and written work.

The ADS collects, preserves and disseminates digital archaeological data for research, teaching and learning purposes. Data is uploaded from commercial and research-based archaeological surveys, and must adhere to strict standards for metadata. The ADS also hosts data collections such as England's Rock Art (ERA), a collection of images of rock art from the Northumberland and Durham area, where some images were taken with the explicit purpose of recording for 3D reconstruction.

BFA is an online archive of aerial photographs, comprising of a collection of over 95,000 images taken between 1919 and 1953 by the Aerofilms aerial surveying company. The archive is the result of a four-year digitising project between RCAHMS, EH and RCAHMW to conserve and digitise the collections from negatives and photograph albums. High resolution (300 dpi) prints can be purchased online, while non-commercial use of the online low resolution images (96 dpi, approximately 580 × 580 pixels) is free.

The PAS is a website run by the British Museum which allows members of the public to submit information and photographs of historically significant objects that they themselves have found. Information can be recorded by anyone, but is curated by trained archaeologists. High resolution images are available for download under a Creative Commons Share-Alike licence (BY-SA)

and are mostly technical compositions of different views of the object against a scale, for example the Neolithic flint implement shown in figure 1 (Basford 2013).

D. The Internet as an Archive

Resources which are not catalogued and archived by trained archaeologists are available through other sources online. An example of a specific resource is the online community of The Megalithic Portal. The Megalithic Portal is an online community of people documenting megalithic sites across the world. The community comprises mainly of the general public, but the photographs provided by members are a valuable resource. Sites such as Wikimedia Commons offer broader and more general subject matter, where users can upload free-to-use images on any subject. An important point to consider of internet resources is that the information is not always free to use or of good quality, but may be an overlooked resource.

IV. CASE STUDIES

To examine the possibilities of using archived images with automated photogrammetry, five example sites have been selected. These sites demonstrate the different levels of success achieved with appropriate sets of photographs, and were selected from dozens of sets which were found to be unsuitable.

Sites were selected through a number of stages:

- 1) archives were searched for site records containing large quantities of images;
- 2) images were visually assessed to estimate likelihood of success based on the photograph overlap and coverage;
- 3) images were obtained from the archive and opened in Agisoft PhotoScan;
- 4) sites were selected based on which were successfully reconstructed, with and without manual intervention.

The sites chosen as case studies are Silbury Hill, Esgair Las inscribed animal head, Beaumaris Castle gatehouse ticket office, a traditional leaf trail wall painting at Ciliau Hall House, and St Lythans burial chamber. Each are described in further detail in the following sections.

Many reconstructions were successful, and the case study sites have been selected to represent different types of photographs, methods of intervention and grades of success in creating the models. Silbury Hill has been chosen as an example of aerial photography from scanned black and white photographs. Esgair Las inscribed animal head as an example of a carving or rock art from digital photographs. Beaumaris Castle gatehouse ticket office represents a building which has been modified since the archived photographs were taken. The wall painting at Ciliau Hall House is used as an example of a set of photographs for producing two comparable models, and St Lythans burial chamber is a single partial reconstruction of mixed medium photographs from different sources.

A. Silbury Hill

1) Site Description: Silbury Hill is an artificial pre-historic earth mound in Wiltshire, UK. It is situated close to the Avebury Henge and West Kennet Long Barrow Neolithic sites and at approximately 160 metres in diameter and 40 metres high, it is one of the largest man-made mounds in the world (Bayliss et al. 2007).

2) Archive Images: BFA holds 13 images of Silbury Hill from 1946, 1947, 1951 and 1953, all in black and white format. Although the site does itself does not visibly change a great deal between the groups of photographs, the landscape around it changes significantly. This is due to the changing seasons; the photographs from 1947 were taken in June and show a dry landscape and full trees (see figure 2), while those taken in the March of 1951 show the quarry at the base filled with dark water (see figures 14(a)–(d)).

3) Results: The four images from March 1951 used to construct a model are shown in figures 14(a)–(d). The



Fig. 1: A Neolithic flint implement found on the Isle of Wight, an example of a typical composite image for recording archaeological finds. Image from the Portable Antiquities Scheme (IOW2013-4-127.jpg).



Fig. 2: Silbury Hill photographed on 11th June 1947, photograph from Britain from Above (EAW007043.jpg).

four photographs alone provided sufficient coverage of the site to achieve the model shown in figure 3. Figure 3 shows the normal map of the model; it is possible to see that some ground detail was extracted despite the small number of low-resolution images and that the details is not simply an illusion from the texture.

The model depicts the site as it was in 1951, prior to the collapse of the top of the mound in 2000 and before site access was restricted to help preserve the mound.

The angle at which the photographs in figures 14(a), 14(b) and 14(c) were taken places the furthest side of the mound in view, which allows the entire mound to be modelled with a small number of photographs.

Additional reconstructions were attempted with the photographs from other years to produce comparable models, but were not successful.

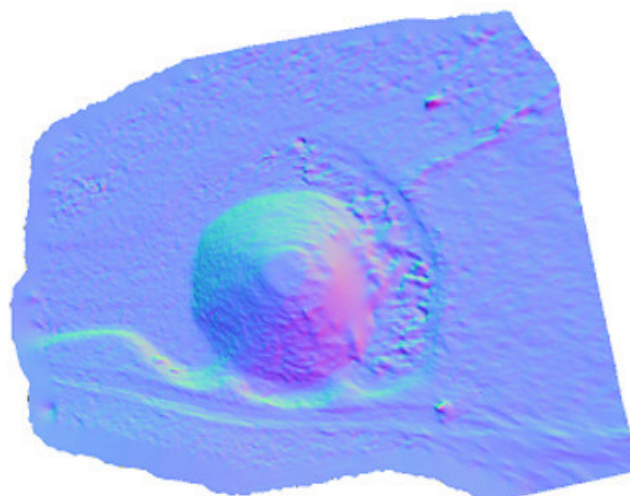
B. Esgair Las Inscribed Animal Head

1) Site Description: An animal head carved into a boulder on the southern side of the Afon Ystwyth valley in Ceredigion, Wales. Shown in figure 4, the depicted animal has been suggested to be a sheep, deer or wolf (Driver 2006). The carving measures around 25 cm tall by 19 cm wide, with the eye measuring 4cm in diameter, and while the age is not known, it is covered in lichen suggesting it is not recent (Driver 2006).

2) Archive Images: Ten images were obtained from Coflein, with a selection of them shown in figure 14(e)–(g). Four of the images were taken focussing close on



(a)



(b)

Fig. 3: (a) The textured model of Silbury Hill. (b) Normal map of the model of Silbury Hill shows the shape of the mound, road and some field boundary details that were extracted from the photographs.

the carving (similar to figure 4), while the others were far shots, either framing the boulder or showing it from a distance.

3) Results: Six images of the images were successfully matched to produce the model shown in figure 4. The low resolution of the online versions of these photographs is likely to blame for the failed feature matching, as in the further shots the carving becomes very a small portion of the image.

It is difficult to discern the geometry due to the texturing of the model and because the rock face is relatively flat. Figure 5?? shows the normal map of the model, on which the contours can be seen more clearly.



(a)



(b)

Fig. 4: (a) Esgair Las animal head carving photographed in 2006, photograph from Coflein (DS2006_084_010.jpg). (b) The model of Esgair Las inscribed animal head.

In an attempt to gain greater resolution on the carving section itself, a second model was created in which the area around the carving was cropped. Despite being created using the same camera positions, the cropping of the sparse point cloud introduced some distortion, which can be seen in the model's normal map shown in figure 5???. Examining the distortion by comparing the two meshes using an approximation of the Hausdorff Distance (Aspert et al. 2002) revealed the differences illustrated in figure 5???. The difference is indicated on a colour scale, where red represents the smallest distance between matched points (0.00 cm) to blue which represents the largest distance between matched points (approximately 0.83 cm).

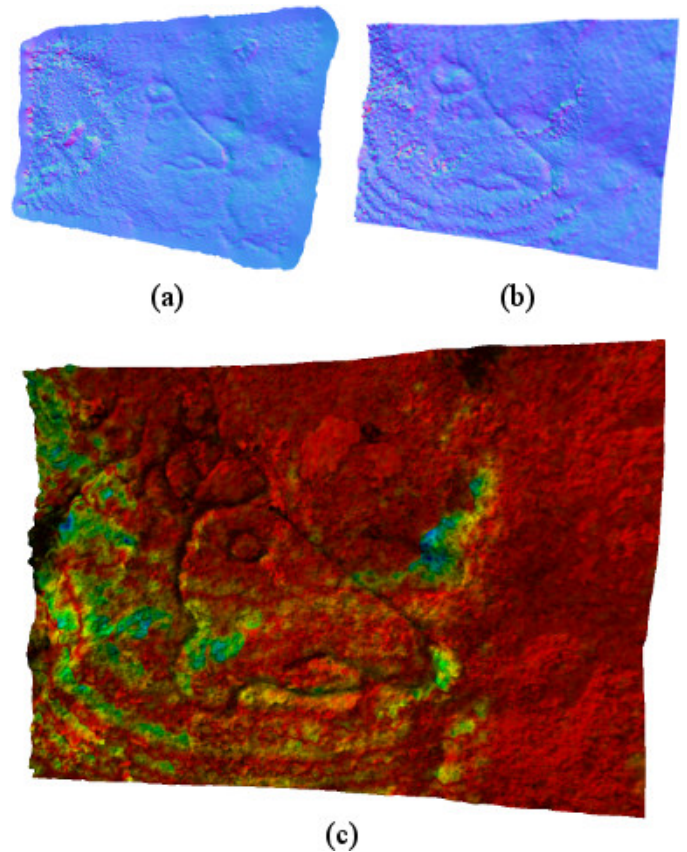


Fig. 5: Difference between the (a) original and (b) cropped models is visible in the normal maps, this difference is shown using a colour scale in (c) where smallest difference is indicated by red, while greatest difference is in blue.

Further reducing the size of the selected region in the sparse point cloud increased the ripple-like distortion in the model. This is believed to be an effect of the low resolution (96 dpi) of the images: when the selected region is small, the sampling size from the image is too pixelated and not enough information is available to approximate depth with low error.

C. Beaumaris Castle Ticket Office

1) Site Description: Beaumaris Castle was constructed on the Isle of Anglesey in North Wales by Edward I between 1295–1330. The castle is accessible via two gatehouses, situated on the north and south sides of the castle (Steele 2008). The southern gatehouse exits next to a road, and a path winds from the gatehouse to the west, where a visitor entrance has been constructed. At this entrance, a ticket office was constructed in 1954; the ticket office is shown shortly after it's construction in figure 6.



Fig. 6: The Beaumaris Castle Ticket Office photographed in 1954, from the D.O.E. Photographic Collection on Coflein (DI2010_2822.jpg).

2) *Archive Images:* Seven images of the ticket office, taken in 1954, are available on Coflein. The photographs are part of the D.O.E. Photographic Collection, a collection of photographs and negatives of a number of Welsh monuments. The photographs are all around 800×800 pixels in size, and are all in black and white, with examples shown in figure 14(h)–(k).

3) *Results:* The model of the ticket office can be seen in figure 7, with normal map shown in figure 7???. Only five of the images were used to construct the model, as one showed the office during construction without a roof, and the other showed the back of the office which could not be matched to the front due to insufficient overlap. As the five remaining photographs were of the same two walls they were successfully matched but as a consequence only a partial model of those two walls could be created.

Four of the photographs were taken from very similar angles, resulting in some details being skewed. Figure 7??? is positioned at a similar viewpoint to the photographs, while in figures 7??? and 7???, the two walls are shown directly to highlight the defects. The windowed wall (figure 7???) and the roof above it have more photographic coverage, resulting in better reconstruction than the wall with the door (figure 7???). The reflections from

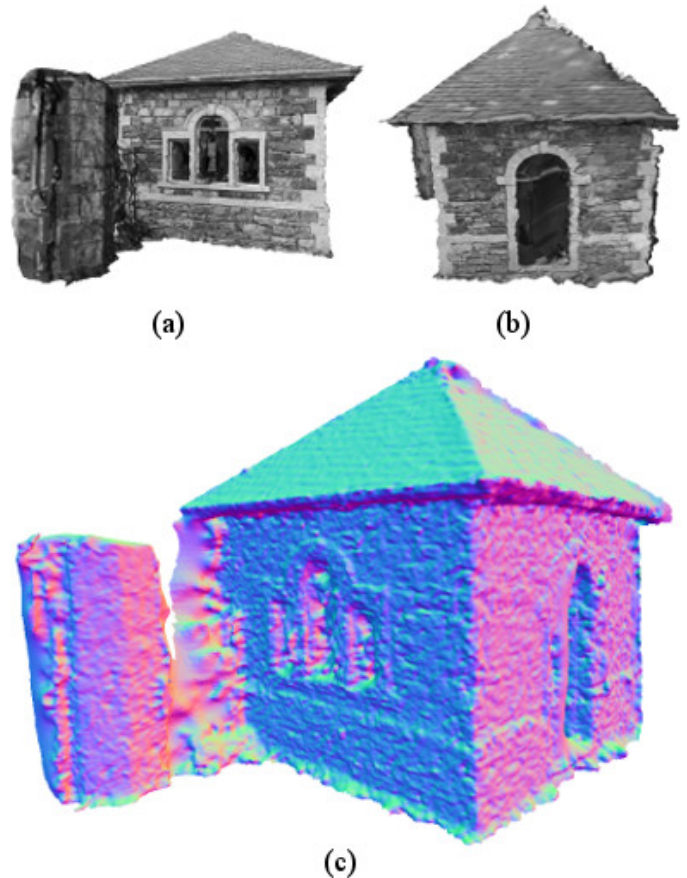


Fig. 7: Partial reconstruction of the Beaumaris Castle ticket office, where only two walls and part of the roof could be modelled.

the glass in the window have caused some distortions in the mesh; the open door is also distorted on the left side, though this is from lack of photographic coverage.

D. Traditional Leaf Trail Wall Painting at Ciliau Hall House, Erwood

1) *Site Description:* Ciliau Hall House is a sixteenth century house in Powys which is very well preserved. In 2004 a wall painting was uncovered on a partition, shown in figure 8; the painting is composed largely of leaf and flower trails, with some animals dispersed throughout the trails. Restoration work was completed on the painting in early 2007 (RCAHMW 2009).

2) *Archive Images:* Coflein holds 30 colour digital photographs of the wall painting: four date from 14 December 2004, with the remaining taken during a digital photographic survey of the house on the 6th February 2007; some examples are shown in figures 14(l)–(o). The images from 2004, such as figure 8, show the painting prior to the restoration work, which had been



Fig. 8: Part of the leaf trail wall painting at Ciliau Hall House, photographed 14 December 2004 prior to restoration work; from Coflein (DI2006_1739.jpg).

completed when the survey photographs were taken in 2007.

3) *Results:* Dividing the set of photographs into two allowed the production of two separate models of the wall: before (figure 9??) and after (figure 9??) the restoration work. The photographs were all taken directly facing the wall, which caused some issues in producing models by affecting depth estimations. There being only four images of the wall pre-restoration resulted in an apparent concave bow in the wall, and the pillar in the centre of the painting has been affected in both models as there is very little coverage of the sides except where it appears on the edges of photographs (as in figure 8). To combat the curving wall, some of the images from 2007 were used alongside the images from 2004 during the alignment stage, then discarded during the dense point cloud creation.

When comparing the two models visually, it is possible to see the restoration work has darkened and remedied most the banding on the extruding panels. The results of comparing the post-restoration mesh to the pre-restoration model are presented in figure 9??. Hausdorff distance was used to approximate distance between corresponding vertices, and is presented visually with a colour map: red is the closest match and blue is the furthest. Here the door area in the right of the scene was not part of the 2004 model, and so is found to be the most different, while most of the wall area is similar.

The normal map of the post-restoration model demonstrates the effects of detailed photographic coverage. In

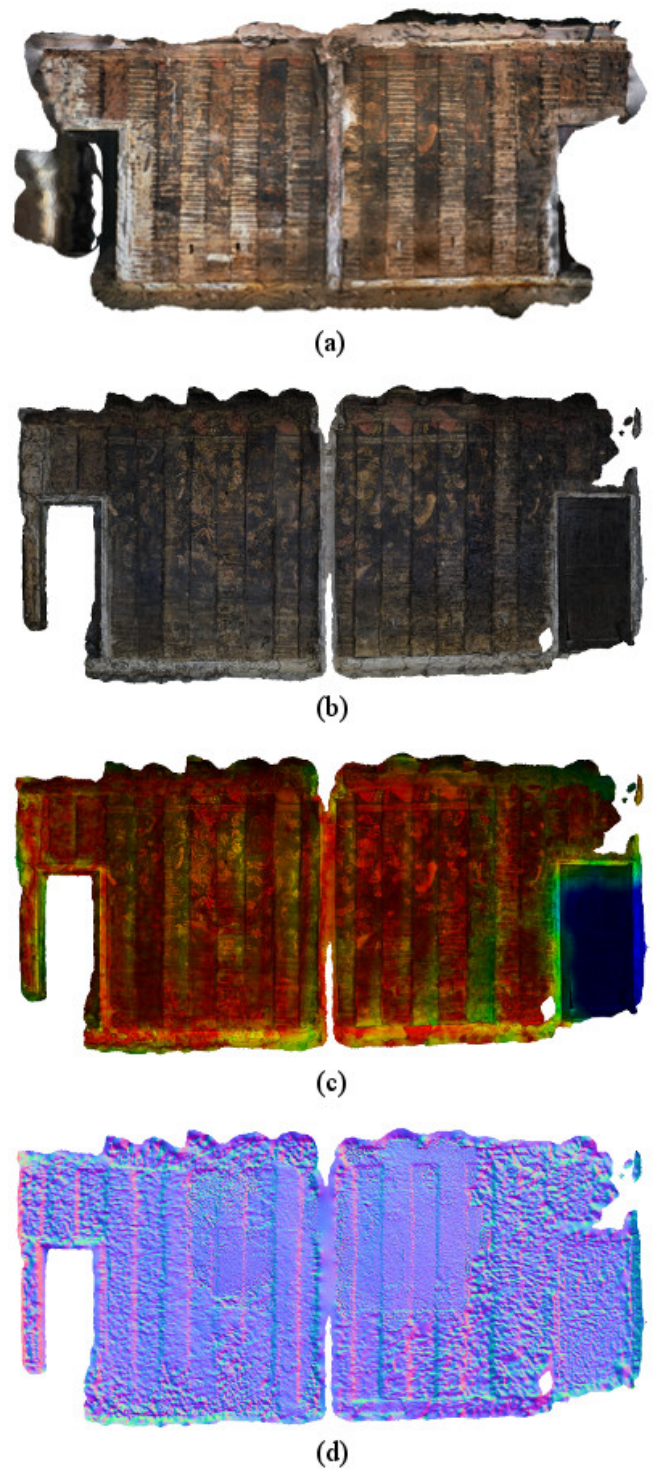


Fig. 9: The model of the leaf trail wall painting. (a) Pre-restoration model from the 2004 photographs. (b) Post-restoration model from the 2007 photographs. (c) Comparison of the post-restoration model to the pre-restoration model using Hausdorff distance to approximate model similarity, red designates closest match through to blue for furthest. (d) Normal map of the post-restoration model.

figure 9?? the areas of the wall which were covered by close-up images of the painting detail have much finer features, while the areas covered only by distant images are noisy and not as well-defined.

5 *E. St Lythan's Burial Chamber*

1) *Site Description:* St Lythans burial chamber, also known as Maes-y-Felin and Gwal-y-Filiast, is a long cairn or barrow in South Wales, where only a dolmen (see figure 10) remains at the eastern end (Driver 2012).

2) *Archive Images:* Unlike the other case studies, a model of this site was initially constructed as part of the HeritageTogether project to record megalithic monuments for the express purpose of creating 3D models. However, photography of the site was incomplete with an entire side of the chamber missing, resulting in the incomplete model shown in figure 11. To attempt to create a more complete model, photographs from several sources were used in combination.

Twenty images from the HeritageTogether collection were used alongside five images from Coflein. The images from HeritageTogether were the original high-resolution digital photographs taken on 3rd July 2014, four of the photographs from Coflein were black and white photographs from the D.O.E. collection taken 27th June 1949, and the fifth is a colour scan of a dia-positive from 1980. Some of the images can be seen in figures 14(p)–(r).

3) *Results:* Initially, the new images could not be matched to the originals as there was not sufficient overlap; to remedy this, a selection of photographs from the Megalithic Portal were used in the image matching



Fig. 10: St Lythans burial chamber, photographed 03 July 2014; from HeritageTogether (P1050363.jpg).

phase. The height of the burial chamber meant that there were no photographs of the top of the capstone, and all of the photographs had to be masked to prevent noise around the top of the capstone.

Once the photographs had been successfully aligned,

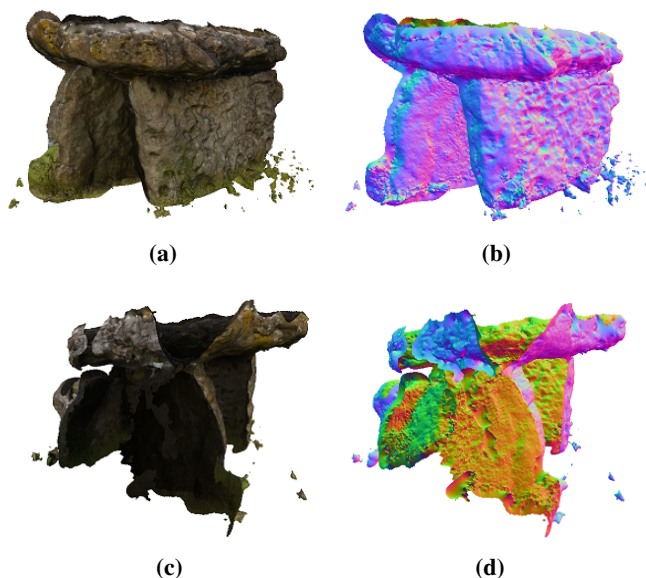


Fig. 11: Original model of St Lythans, with large portion of wall missing. Two views of the model are shown in (a) and (c), accompanied by the normal maps in (b) and (d) to highlight the geometry.

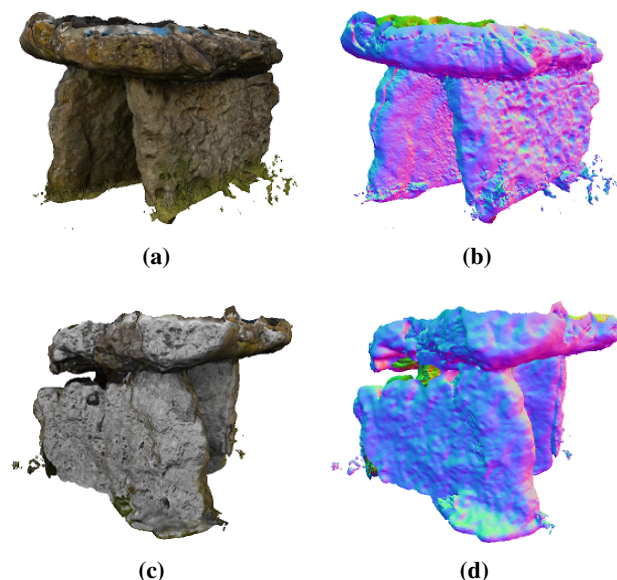


Fig. 12: New model of St Lythans; new wall segment can be seen with black and white texturing. Two views of the model are shown in (a) and (c), with normal maps in (b) and (d).

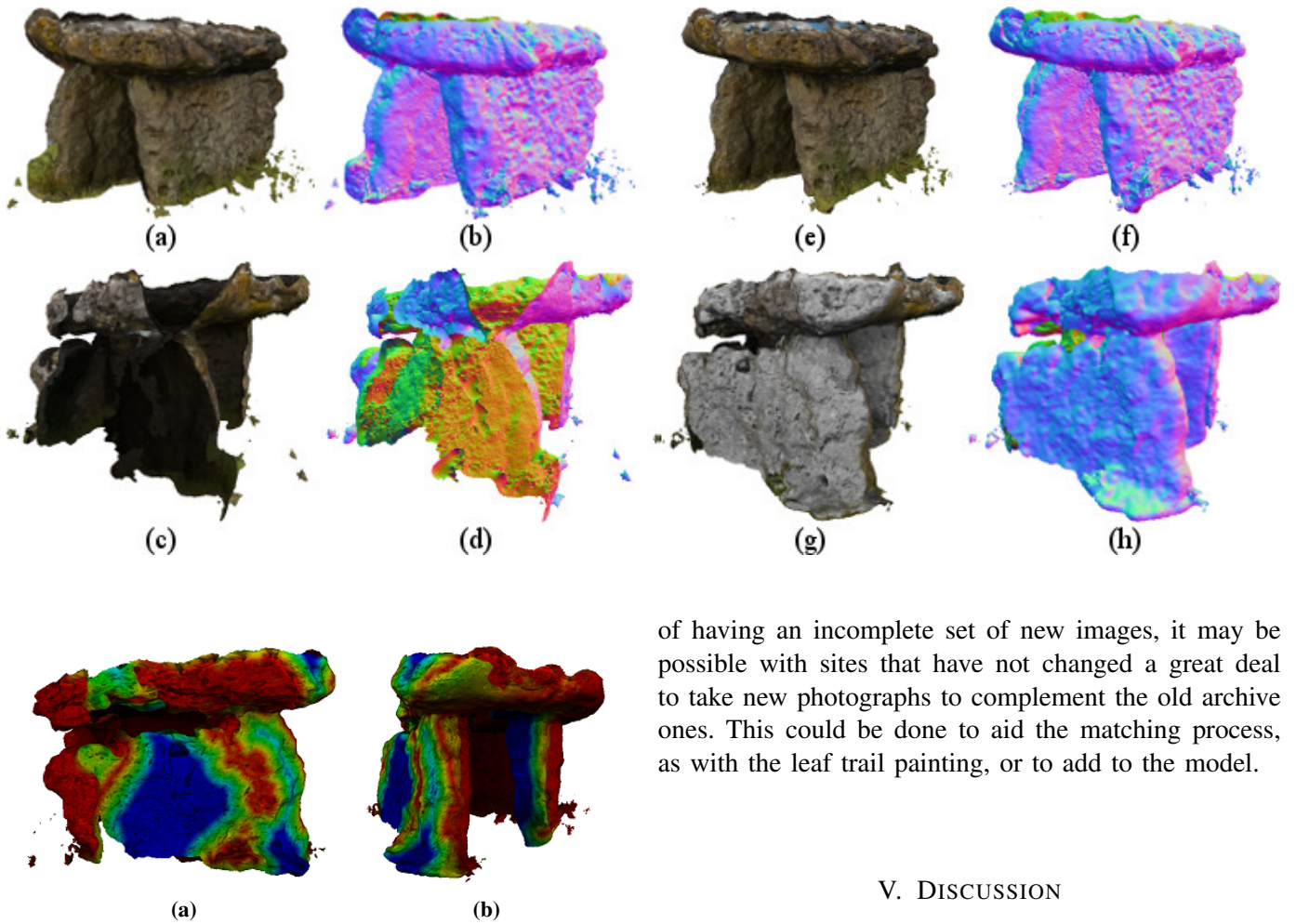


Fig. 13: Comparison of the two models using Hausdorff distance; similarities between the two models are estimated and represented by colouring the vertices. The red portions of the model are the closest match, where the original model remains intact, and blue for most distant match, which shows the new vertices of the model.

the missing outer wall of the chamber was reconstructed, with the new model shown in figure 12. It is possible to see that the new wall is mostly textured from the black and white images. Comparing the new model to the original using Hausdorff Distance to colourize the vertices (figure 13), it is possible to see the original model is coloured red where no little or not difference is detected, to blue which shows the furthest distance between matched vertices.

This serves as an example of combining material from multiple archives and from different mediums—high-resolution digital photographs, scanned dia-positives and black and white images.

While the site was approached from the perspective

of having an incomplete set of new images, it may be possible with sites that have not changed a great deal to take new photographs to complement the old archive ones. This could be done to aid the matching process, as with the leaf trail painting, or to add to the model.

V. DISCUSSION

The case studies each provide a different perspective on the use of archival images to create 3D models. The exploration of these photographs leads to some research questions, which will now be discussed in turn.

- A. Do photographic archaeological archives regularly contain multiple images of the same heritage asset taken from different angles and distances?
- B. Are these images of sufficient quality to allow for 3D rendering in automated 3D photogrammetric software?
- C. Are not born-digital images of such sufficient quality after having been scanned in from negatives or dia-positives?
- D. What amount of processing or editing of images is required to improve image quality sufficiently for automated 3D model creation?
- E. Do sufficient numbers of high-quality images exist of damaged or destroyed objects, sites and monuments to re-create the three-dimensionality of these lost heritage assets?

A. Do photographic archaeological archives regularly contain multiple images of the same heritage asset taken from different angles and distances?

Exploring the archives searching for suitably-photographed sites proved to be a difficult task. Sources of photographs were numerous, but often didn't contain enough images of a single site, or images which were taken with too little overlap, where sites were photographed from completely different directions. Additionally, when photographing the site, it appears the photographers often chose a visually-pleasing position to take the photograph from, and as a result many sites were captured from almost the same view in multiple shots.

Aerial photography was found to work reasonably well as in many cases several photographs were taken whilst flying around the subject, providing enough coverage to create models. Silbury Hill demonstrates a case where the shape of the subject aided the process: the mound is a relatively simple shape, and the photographs—despite being taken from similar angles—were taken from high enough to see past the top of the mound and the down the masked side. This resulted in the texture being pixelated and of much lower quality on the masked side of the mound, but the mesh shape has been approximated without appearing to be visibly noisy or distorted. Several attempts were made to model buildings (e.g. castles) from aerial photography, but produced models were noisy and visibly warped; this is thought to be a result of the complex shape of the building and not enough photographs to calculate the complexity in sufficient detail.

Shape of the subject also appears to affect ground-level photography. When searching for an example of a building, many examples of well-photographed façades were found that could not be used. The Beaumaris Castle ticket office was photographed several times from the same visually-pleasing viewpoint, which, for the ticket office, was facing two of the walls diagonally. This meant that the two walls could be seen well in most of the photographs, and there was sufficient variation in the angle to estimate the structure of the two walls.

Despite full photographic coverage of finds and artefacts in technical compositions, such as those from the PAS, there is not enough overlap between the images to reconstruct 3D models. In the example image in figure 1, the front, back and sides have been photographed directly; processing the images and placing them in front of a white background allows for easy masking, but the

lack of overlap makes it impossible for PhotoScan to match the images.

B. Are these images of sufficient quality to allow for 3D rendering in automated 3D photogrammetric software?

The images from many online photographic archives, for example Coflein and BFA, may have original photographs in high resolution maintained locally, but only provide images of reduced resolution online. The lower resolution reduces not only the image dimensions but also the storage size and the quality. Images which were born-digital are also reduced in resolution; the processing strips any Exif data contained in the original image file. Exif data is additional metadata attached to JPEG and TIFF files, containing information on the camera model, lens, zoom used, and more. PhotoScan uses this information during photo alignment to allow better estimation of the position at which the photographs were taken, and generate a more accurate sparse point cloud. Despite the reduction in quality and removal of Exif data, all of the case studies presented in this paper successfully used these low-resolution images in reconstructions.

It is possible to manually intervene with the reconstruction by masking the images and using additional images during the matching phase. Additional images used during the matching process can help to more accurately align the photos, before discarding them during dense point cloud construction. This can only be used in a situation where the subject has not changed a great deal, as with the leaf trail painting, where the the paintwork was altered but the wall structure was not.

C. Are not born-digital images of such sufficient quality after having been scanned in from negatives or dia-positives?

Images that have been scanned in from negatives or dia-positives can be of sufficient quality if treated correctly during processing. The first case study of Silbury Hill serves as an example of successfully creating a model from photographs that were not born digital but have been digitised. The images from BFA are all from the Aerofilms collection, and have undergone conservation and scanning to be presented on the website. It is possible to see variations of success: the majority of the images are of good quality, but nearly 3000 damaged negatives have been scanned and uploaded.

D. What amount of processing or editing of images is required to improve image quality sufficiently for automated 3D model creation?

When collecting images from online archives, no processing of the images is performed. Photographs available from the online archives may be scanned from negatives, dia-positives or original photographs. The scanned images may undergo pre- and post-scanning processing, for example, images from the BFA website are cleaned and treated as negatives, scanned, then digitally restored using Adobe Photoshop.

The images from several online archives have been shown to be of sufficient quality to produce the case studies; any additional processing of the images does not appear to be required as the difficulty in creating the models lies in the lack of images from different angles with enough overlap.

E. Do sufficient numbers of high-quality images exist of damaged or destroyed objects, sites and monuments to re-create the three-dimensionality of these lost heritage assets?

When searching for sites to attempt reconstruction, priority was given to sites which are known to have been damaged or destroyed since the photographs were taken. None of the chosen case studies have since been lost to destruction, but some have changed. Since Silbury Hill was photographed in 1951, the top of the mound has collapsed and been restored; site access has also become very restricted. The Beaumaris Castle ticket office has been modified, though the greatest modification is to a wall that was not successfully reconstructed (opposite the wall with the door). The leaf trail painting was reconstructed both before and after restoration work, with visibly comparable differences in the texture.

It is possible that examples exist where enough photos of a destroyed site would allow the creation of a model, but none were found during the search for suitable case studies.

VI. CONCLUSION

Exploring the potential use of archived images to create 3D models using an automated photogrammetry pipeline in Agisoft PhotoScan, we have reconstructed five subjects as case studies with varying levels of success. The success of the model depends of a number of factors: whether the images overlap, how much of the site they cover, the angles at which the photographs were taken and the shape and complexity of the site in question.

Aerial photography often provides more coverage from different positions around the site as the aeroplane was circling the site, and as such was found to work well. Conversely in ground photography sites are often photographed repeatedly from the same visually-pleasing angle.

The shape of the subject also appears to relate to success, because photographing objects with rounded edges often results in unintentionally capturing more overlap, whereas sharp edges and corners in photographs of buildings mask the side around the corner. An exception to this was found during construction of the Beaumaris Castle ticket office, where the corner between two walls was at the centre of most of the photographs. Only two of the walls benefited from this, the other two were completely masked, and the one photograph available of a third wall could not be matched to the others.

We have demonstrated that it is possible to reconstruct heritage sites as 3D models from archived 2D images when there is a sufficient number of photographs taken from different angles. Unfortunately, it is more often the case that not enough photographs exist, or they do not provide suitable coverage of the site to produce a full model, though it may be possible to get partial reconstructions.

VII. ACKNOWLEDGEMENTS

We acknowledge the AHRC (UK) AH/L007916/1 for funding “co-production of alternative views of lost heritage of Gwynedd”, and would like to thank the following for the use of their photographs:

Portable Antiquities Scheme

Lithic Implement, 2013: Frank Basford
<http://finds.org.uk/database/artefacts/record/id/578150>

Britain From Above

Silbury Hill, Avebury, 1947 and 1951:
www.britainfromabove.org.uk/image/EAW007043
www.britainfromabove.org.uk/image/EAW034892
www.britainfromabove.org.uk/image/EAW034894
www.britainfromabove.org.uk/image/EAW034895
www.britainfromabove.org.uk/image/EAW034896

Royal Commission on the Ancient and Historical Monuments of Wales

Esgair Las inscribed animal head, 2006:
Digital photographic survey by Toby Driver;
<http://coflein.gov.uk/en/site/404279/>

Beaumaris Castle, 1954:

D.O.E. Photographic Collection;
<http://coflein.gov.uk/en/site/95769/>

Ciliau Hall House, 2004 and 2007: Digital photographic
survey and colour transparencies by Iain Wright;
<http://coflein.gov.uk/en/site/81106/>

St Lythans, 1949: D.O.E. Photographic Collection;
<http://coflein.gov.uk/en/site/227289/>

REFERENCES

- Agisoft PhotoScan (Last visited: 11/12/14).
URL: <http://www.agisoft.com>
- Archaeology Data Service (ADS) (Last visited: 10/12/14).
URL: <http://archaeologydataservice.ac.uk>
- Archwilio (Last visited: 04/12/14).
URL: <http://www.archwilio.org.uk>
- Aspert, N., Santa Cruz, D. & Ebrahimi, T. (2002), MESH: measuring errors between surfaces using the Hausdorff distance., in 'ICME (1)', pp. 705–708.
- Basford, F. (2013), 'Portable Antiquities Scheme: Lithic Implement, ID: IOW-57C4D6'.
URL: <http://finds.org.uk/database/artefacts/record/id/578150>
- Bayliss, A., McAvoy, F. & Whittle, A. (2007), 'The world recreated: redating Silbury Hill in its monumental landscape', *ANTIQUITY-OXFORD*- **81**(311), 26.
- Britain From Above (BFA) (Last visited: 11/12/14).
URL: <http://www.britainfromabove.org.uk>
- Cadw (Last visited: 11/12/14).
URL: <http://cadw.wales.gov.uk>
- Coflein (Last visited: 12/12/14).
URL: <http://coflein.gov.uk>
- Driver, T. (2006), 'Esgair Las Inscribed Animal Head'.
URL: <http://www.coflein.gov.uk/en/site/404279/>
- Driver, T. (2012), 'St Lythans Chambered Long Cairn, Maesyfelin; Gwal-Y-Filiast; Maes-Y-Felin'.
URL: <http://www.coflein.gov.uk/en/site/227289/>
- England's Rock Art (ERA) (Last visited: 04/12/14).
URL: <http://archaeologydataservice.ac.uk/era>
- English Heritage (EH) (Last visited: 05/12/14).
URL: <http://www.english-heritage.org.uk>
- Grussenmeyer, P. & Yasmine, J. (2004), 'Photogrammetry for the preparation of archaeological excavation. A 3D restitution according to modern and archive images of Beaufort Castle landscape (Lebanon)', *Archives of Photogrammetry and Remote Sensing* pp. 809–814.
- Gwynedd Archaeological Trust (GAT) (Last visited: 11/12/14).
URL: <http://www.heneb.co.uk>

HeritageTogether (Last visited: 12/12/14).

URL: <http://heritagetogether.org>

Kalisperakis, I., Rova, M., Petsa, E. & Karras, G. (2003), On multi-image reconstruction from historic photographs, in 'XIX CIPA International Symposium, Antalya', pp. 216–219.

Orengo, H. A. & Fiz, I. (2007), The application of 3d reconstruction techniques in the analysis of ancient tarracos urban topography, in 'Layers Of Perception. Proceedings Of The 35th International Conference On Computer Applications And Quantitative Methods In Archaeology (CAA), Berlin'.

People's Collection Wales (PCW) (Last visited: 05/12/14).

URL: <http://www.peoplescollectionwales.co.uk>

Portable Antiquities Scheme (PAS) (Last visited: 11/12/14).

URL: <http://finds.org.uk>

RCAHMS (2009), 'Ciliau Hall House, Erwood'.

URL: <http://www.coflein.gov.uk/en/site/81106/>

Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS) (Last visited: 03/12/14).

URL: <http://www.rcahms.gov.uk>

Royal Commission on the Ancient and Historical Monuments of Wales (RCAHMS) (Last visited: 11/12/14).

URL: <http://www.rcahmw.gov.uk>

Steele, K. (2008), 'Beaumaris Castle'.

URL: <http://www.coflein.gov.uk/en/site/95769/>

The Megalithic Portal (Last visited: 10/12/14).

URL: <http://www.megalithic.co.uk>

Walstra, J., Dixon, N. & Chandler, J. H. (2007), 'Historical aerial photographs for landslide assessment: two case histories', *Quarterly Journal of Engineering Geology and Hydrogeology* **40**(4), 315–332.

Wikimedia Commons (Last visited: 08/12/14).

URL: <http://commons.wikimedia.org>



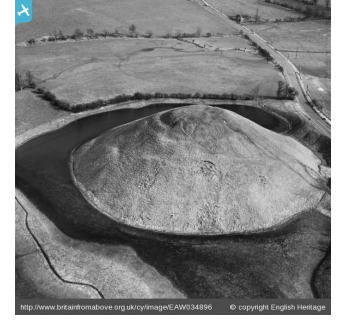
(a) EAW034892.jpg



(b) EAW034894.jpg



(c) EAW034895.jpg



(d) EAW034896.jpg



(e) DS2006_084_004.jpg



(f) DS2006_084_006.jpg



(g) DS2006_084_008.jpg



(h) DI2010_2815.jpg



(i) DI2010_2816.jpg



(j) DI2010_2818.jpg



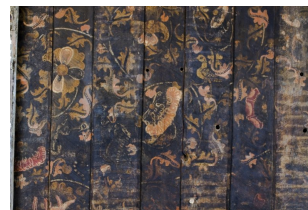
(k) DI2010_2819.jpg



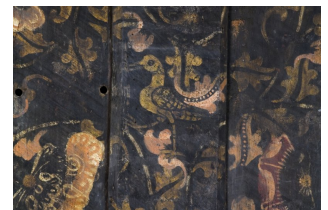
(l) DS2007_024_001.jpg



(m) DS2007_024_014.jpg



(n) DS2007_024_017.jpg



(o) DS2007_024_019.jpg



(p) P1050360.jpg



(q) DI2010_2410.jpg



(r) P1050377.jpg

Fig. 14: Examples of the images used for the five case studies:

(a)–(d) Silbury Hill (Britain From Above, 1951); (e)–(g) Esgair Las inscribed animal head (Coflein, 2006); (h)–(k) Beaumaris Castle gatehouse ticket office (Coflein, 1954); (l)–(o) Ciliau Hall House leaf trail painting (Coflein, 2004); and (p)–(r) St Lythans burial chamber (HeritageTogether.org, 2014; Coflein, 1949).